THE EFFECTS OF DEPTH AND HARVEST ON BAIT FISH IN SOUTHERN ONTARIO STREAMS

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Ministry of Natural Resources
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THE EFFECTS OF DEPTH AND HARVEST ON BAIT FISH IN SOUTHERN ONTARIO STREAMS

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ABSTRACT

Portt, C.B. 1984. The effects of depth and harvest on bait fish in southern Ontario streams. Ont. Fish. Tech. Rep. Ser. No. 15: iii & 22p.

Total fish biomass and bait fish biomass were estimated at 18 locations in southern Ontario streams. Both were significantly correlated with mean depth ($p<0.01$), as was fish abundance ($p<0.05$). Bait fish biomass was significantly correlated with total fish biomass ($p<0.01$).

Three successive harvests in the same year at two locations showed similar declines in biomass. Changes in abundance varied between species. Evidence is presented to suggest that the harvest of bait fish can decrease the biomass present in the following year. Implications for management and further research are discussed.

Keywords: bait fish, streams, depth, habitat, harvest, cyprinids, biomass, abundance

THE EFFECTS OF DEPTH AND HARVEST ON BAIT FISH IN SOUTHERN ONTARIO STREAMS

INTRODUCTION

The bait fish industry in Ontario is significant in terms of both employment and revenue (Wallace 1976), and it provides a service which many anglers desire. Retail sales of bait fish within the Province of Ontario were estimated to be in excess of $12.4 million in 1980 (Bedi and Clifford 1982). Management of the bait fish resource is the responsibility of the Ontario Ministry of Natural Resources; however, Desjardine (1978) noted that management of the resource was "plagued by a paucity of sound data upon which management decisions can be based". This study examines the relationships between total fish biomass, bait fish biomass, and depth in southern Ontario streams. Preliminary investigations of the effect of harvest on bait fish abundance were also carried out.

MATERIALS AND METHODS

SITE SELECTION

Biomass was estimated at 18 sites in southern Ontario (Table 1). Site selection was strongly influenced by the gear which was used to collect the fishes: seines and an electrofisher. Streams had to be shallow enough to wade using chest-waders, relatively free of obstructions to seining such as logs and stumps, and narrow enough that a 9.1 m (30 ft.) seine would reach completely across. The first two constraints also influence the choice of harvest locations by commercial bait fishermen who use seines. The latter does not. Sampling locations were restricted to non-salmonid streams in order to reduce variation in biomass which may occur due to differences in stream temperature.

COLLECTION OF FISHES AND ESTIMATES OF BIOMASS AND ABUNDANCE

At each site the designated section of stream was blocked off using 3 mm mesh seine nets stretched from bank to bank. A seine was then pulled repeatedly through the section, while the anode of a generator-powered electrofisher was maintained behind the 'bag' of the seine. Following each seining, the fish captured were preserved in 10% formalin. Seven seinings were made at each site except SR1 and JR1, where five were made.

The fish in each catch were identified according to Scott and Crossman (1973) and their standard length was measured to the nearest millimeter. Most species were separated into two or more length groups, which corresponded roughly to one or more age classes (based on length frequencies). The combined weight of all individuals in each length group was determined to the nearest 0.1 g.

The number of individuals in each section was estimated using the method of Leslie and Davis (1939). Each seining was considered to be one unit of fishing effort. Where units of fishing effort are equal:

$$C_t = q\,N_0 - q\,K_t$$

where

C_t = fish captured in catch t,

K_t = the cumulative number of fish captured in previous catches,

N_0 = the original number of fish in the section

q = catchability.

A regression of catch versus cumulative catch was fitted using the method of least squares, and its significance was tested using an F-test (Steel and Torrie 1960). Confidence limits were calculated using the method of Ricker (1975). Where no fish in a particular length group were captured in the last three catches it was assumed that all of the individuals had been captured. Where this was not the case estimates were considered satisfactory if the regression of catch versus cumulative catch was significant ($p<0.10$). If the estimate was unsatisfactory the number of individuals captured was used as an estimate of the minimum number of individuals present. Sites where more than 10 percent of the estimated total biomass was derived from unsatisfactory estimates were eliminated from subsequent analyses.

In Ontario, bait fish are legally defined as including mudminnows (Umbridae), suckers (Catostomidae), sticklebacks (Gasterosteidae), sculpins (Cottidae), darters (Percidae, subfamily Etheostomatinae), minnows (Cyprinidae) excluding carp (*Cyprinus carpio*) and goldfish (*Carassius auratus*), ciscoes (subgenus *Leucichthys*, genus *Coregonus*), and trout-perch (*Percopsis omiscomaycus*). Informal interviews with anglers indicated that "suckers and shiners" were the preferred species. Bait fishermen indicated that there was no market for sticklebacks, sculpins, or darters. Therefore, these species were not included in estimates of saleable biomass. Size groups which contained no fish larger than 50 mm (standard length) or with a mean weight less than 3 g were also not included, as these were considered too small by most anglers.

SITE CHARACTERISTICS

Each site was measured immediately after the last fishing was completed. A measuring line was stretched parallel to the stream. At five meter intervals along this base line the perpen-

dicular distances to both banks, the distances to ten centimeter depth intervals, and the maximum depth were measured. The coordinates were plotted and the stream banks and ten centimeter isobaths were drawn. The length of the banks, the total area of each site, and the area within each isobath were determined using an electronic planimeter. Volume was calculated using the formula:

$$V = \Sigma \left(A_i - A_{i+1}\right) \times \frac{d_i + d_{i+1}}{2}$$

where

V = volume,

A_i = the area inside the ith isobath, and

d_i = the depth of the ith isobath.

Water samples were collected from all sites on October 11 and 12, 1981. Total alkalinity was determined using the inflection point method and total hardness was determined by EDTA titration (Standard Methods). Conductivity was determined using a temperature compensating conductivity meter (Yellow Springs Instruments, Model No. 33). All chemical parameters were determined on the day that the water samples were collected. TDS was derived from conductivity using the conversion of Dodge *et al.* (1979).

THE EFFECTS OF REPEATED HARVESTS IN THE SAME YEAR

During 1981, biomass was estimated on three occasions, approximately 4 weeks apart, at two locations (GC1 and LC2). The estimates were carried out in the manner described in the preceeding section. The efficiency of the sampling technique was such that each biomass estimate closely approximated 100 percent harvest.

THE EFFECTS OF HARVEST IN THE PREVIOUS YEAR

All of the fish captured during biomass estimates were preserved for later analysis, so the estimates themselves constitute a 'harvest'. At two locations sampled in 1980 (JR1 and 2, SR2), additional fish were removed by seining several days after biomass was estimated. Biomass was estimated again at these sites, as well as at two sites where no additional fish were removed, in 1981.

RESULTS

SITE CHARACTERISTICS

Sites ranged from 42.2 m^2 to 241.8 m^2 in area, and from 0.11 m to 0.60 m in mean depth (Table 2). Total alkalinity and total hardness were within the expected range for streams in southern Ontario, and total dissolved solids ranged from 279 $mg \cdot \ell^{-1}$ to 536 $mg \cdot \ell^{-1}$.

SPECIES COMPOSITION

A total of 29 species were encountered at one or more of the 18 sites (Table 3). Creek chub (*Semotilus atromaculatus*) were present at all sites and white suckers (*Catostomus commersoni*) were present at all sites but one. Two species, the Iowa darter (*Etheostoma exile*) and the redside dace (*Clinostomus elongatus*) were present at only one site. The most species encountered at any one site was 16 and the fewest was 5 (mean = 11).

BIOMASS, ABUNDANCE, AND MEAN WEIGHT

The estimated total biomass ($\hat{B}_T$) ranged from 3.3 $g \cdot m^{-2}$ to 247.3 $g \cdot m^{-2}$ (Table 4). The estimated saleable biomass ($\hat{B}_E$) ranged from 0 $g \cdot m^{-2}$ to 208.2 $g \cdot m^{-2}$. B_E accounted for 0% to 98% of $\hat{B}_T$. Estimated abundance per m^2 surface area ranged from 1.1 to 55.8 individuals and mean fish weight ranged from 0.7 g to 14.5 g.

A regression of the log of mean depth ($\bar{d}$) versus log $\hat{B}_T$ was significant ($p<0.01$, $r^2 = 0.74$; Figure 1, Table 5). Site HR2 was eliminated from the examination of the relationship between saleable biomass and mean depth. The presence of saleable biomass at HR2 in 1981 indicated that the absence of saleable biomass in 1980 was an anomaly. A regression of log $\bar{d}$ versus log ($\hat{B}_E + 1$) for the remaining 17 sites was significant ($p<0.01$, $r^2 = 0.77$; Figure 2, Table 5). Data from HR2 were also excluded from a regression of log $\hat{B}_T$ versus log ($\hat{B}_E + 1$) which was significant ($p<0.01$, $r^2 = 0.96$; Figure 3, Table 5).

Biomass is equal to abundance multiplied by mean weight. A regression of mean depth versus the log of abundance was significant ($p<0.05$, $r^2 = 0.485$; Figure 4, Table 5). Regressions of mean depth versus the log of mean weight and of the log of mean depth versus the log of mean weight were not significant ($p>0.10$).

THE EFFECTS OF REPEATED HARVESTS IN THE SAME YEAR

The overall trend was for both numbers and biomass to be reduced in successive harvests (Figure 5); however, the response varied between species (Tables 6 and 7). At both locations, the dominant species in terms of biomass showed a decline with harvest. At GC1, brook sticklebacks (*Culaea inconstans*) increased in numbers by over ten-fold between the first and second harvest, and was the most abundant species in harvests two and three.

At LC2 the proportion of total biomass which was saleable remained constant at 97-98 percent. At GC1, the proportion of total biomass which was saleable declined from 85 percent in the first harvest to 75 percent in the second harvest, and increased to 88 percent in the third harvest.

Mean fish weight varied by less than 15 percent at LC2. At GC1, mean fish weight was 48

percent lower in the second harvest and 41 percent lower in the third catch. Much of this decline was due to the increase in the abundance in sticklebacks. When these were eliminated, mean weight varied by ±11 percent.

THE EFFECTS OF HARVEST IN THE PREVIOUS YEAR

In 1980, a total of 12,123.5 g of fish was removed from a section of the Jersey River which was approximately 200 m long and included sites JR1 (upper boundary) and JR2 (lower boundary). Eighty-seven percent of this was removed during biomass estimates on August 7, with the remainder being removed by seining on August 27. In 1980, a total of 3488.7 g of fish was removed from a 150 m section of a tributary to the Schomberg River which included site SR2. Of this, 66 percent was removed during the biomass estimate on August 14 and the remainder was removed by seining on August 27.

Both total and saleable biomass were lower at JR2 and SR2 in 1981 than in 1980 (Tables 8 and 9). Total abundance declined at JR2, but increased at SR2. Bait-fish abundance decreased at both locations. At JR2, only fathead minnows (*Pimephales promelas*) and northern redbelly dace (*Chrosomus eos*) increased in abundance. At SR2, there was an increase in the abundance of the smallest size classes of most species, but a decline in the abundance of the larger size classes.

At two 'control' locations, where no additional fish were removed by seining, biomass was higher in 1980 than in 1981 (Tables 10 and 11). Abundance increased at SR3, but decreased at HR2. Once again, the changes varied between species and size classes.

DISCUSSION

THE EFFECTS OF STREAM DEPTH

This study indicates that both total and saleable biomass increase exponentially with mean depth, and that the most predictable cause of this increase is an increase in abundance. The lack of correlation between mean depth and mean fish weight is surprising. Several authors have reported that younger, smaller fish inhabit shallower water (Thompson and Hunt 1930, Gibbons and Gee 1972, Moshenko and Gee 1973, Kolder *et al.* 1974, Mathews and Hill 1979). The lack of correlation in this study may be due to differences in species composition between streams. In all cases where more than one site was sampled on the same reach of stream, mean fish weight was greater at the deeper site (Figure 6).

The reason(s) for the increase in biomass and abundance with depth is not known. It may be simply the result of increasing habitat volume. Other factors such as water velocity and substrate, which tend to be correlated with depth, may be ultimately responsible. Predation by avian predators almost certainly decreases with depth, but the significance of avian predation is unknown. Based on this study, it does not appear that an increase in the number of species present is responsible (Figure 7), although other authors have reported that fish species diversity increases with depth (Sheldon 1968, Molles 1978).

Equation 2 (Table 5) predicts that saleable biomass will be zero at depths less than 0.075 m. Equation 3 predicts that saleable biomass will be zero when total biomass is less than 1.84 $g \cdot m^{-2}$. Substituting this value into Equation 1 indicates that this biomass would be present at a depth of 0.076 m. We may, therefore, conclude that these equations are compatable at shallow depths. At depths exceeding the range examined in this study, the results are less than satisfactory. Equations 3 and 1 predict that saleable biomass will exceed total biomass at depths greater than 0.99 m, while Equations 1 and 2 predict that this will occur at depths greater than 0.66 m (Figure 8). It is, by definition, impossible for saleable biomass to be greater than total biomass. Clearly, the regression equations should not be used to make predictions at depths greater than those examined in this study.

THE EFFECTS OF REPEATED HARVESTS IN THE SAME YEAR

The effects of repeated harvests on saleable biomass were similar at sites LC2 and GC1, with estimated biomass in the second harvest being 40 percent and 44 percent of that in the first harvest, respectively. The estimated saleable biomass in the third harvest was 27 percent and 25 percent of that in the first harvest for LC2 and GC2, respectively. The fact that the responses were so similar, in spite of differences in species composition, depth, and initial biomass, suggests that this response might be expected in other streams. However, there were differences in the manner in which individual species responded at the two sites. For example, the biomass of creek chub declined in successive harvests at GC1, but was lowest in the first harvest at LC2. Blacknose dace (*Rhinichthys atratulus*) decreased in number at LC2, but increased at GC2. Such variation in responses between streams may be a reflection of differences in habitat or in species composition outside the harvested area.

The overall decline in numbers and biomass in this study contrasts with the results of Larimore (1954), who found that the number and biomass of minnows increased between May and August when approximately 50 percent of the minnows present were killed at each harvest. Larimore also reported a consistent decrease in mean weight, which was not evident in this study. These differences may have arisen due to the greater proportion of fish which were killed in this study (approximately 100 percent).

The results of this study also conflict with those of Brandt and Schreck (1975), who reported no significant difference ($p<0.05$) in post-harvest bait fish density between 50 meter sampling sta-

tions which were harvested throughout one summer and those which were not. However, Brandt and Schreck had no data on pre-harvest densities, and no barriers to migration were present between harvested and unharvested sections. It is possible that the fishes present in their study area redistributed themselves among harvested and unharvested sections, making the effects of harvest impossible to detect.

The total harvest from LC2 and GC1 was equal to approximately 1.7 times the estimated biomass present at the time of the first harvest. Because harvest approached 100 percent of the biomass present on each occasion, the bulk of successive harvests were fish which had immigrated from other locations within the stream. The effects of harvest, therefore, must have extended beyond the harvest site proper, but the distance over which these effects occurred is unknown.

THE EFFECTS OF HARVEST IN THE PREVIOUS YEAR

At first glance, the results of this study appear straightforward. Biomass decreased at JR2 and SR2 where additional fish were harvested, and increased at HR2 and SR3 where no additional fish were harvested. However, the data must be interpreted with caution. Fish were removed from all four sites in order to estimate biomass. In addition, the two 'control' sites were considerably shallower and had a much lower biomass than the 'harvested' sites. Still, the consistent results suggest that harvest did affect biomass the following year.

These results are, again, in contrast to those of Larimore (1954), who found that minnow density and biomass increased during four years of harvest. Larimore used a 6.3 mm mesh seine, which meant that he did not capture fishes shorter than 46 mm. In this study, a 3 mm mesh seine was used and the minimum size captured was 20 mm. This may account for the contrasting results. However, the mean fish weight in the August collections of Larimore's study showed a steady decrease (1950 = 4.3 g, 1951 = 3.8 g, 1952 = 3.1 g, 1953 = 2.7 g), which suggests that harvest was indeed having an effect on the fish populations.

RECOMMENDATIONS

MANAGEMENT

The regression models developed in this study can be used in combination with knowledge of stream dimensions to predict bait fish biomass, providing that the following constraints are recognized:

1. The regressions apply to streams ranging from 0.11 m to 0.64 m in mean depth.

2. They apply to hardwater streams in southern Ontario.

3. They apply to streams where game fishes are rare or absent.

4. They do not apply to cold-water streams (salmonids present).

The relationships between biomass and depth indicate that activities which reduce mean depth, such as channelization and allowing cattle access to streams, will reduce bait fish biomass. Resource managers should endeavour to prevent such activities if they wish to maintain bait fish production at its present level. Similarly, stream rehabilitation, particularly techniques which increase mean depth, may have the potential to increase the amount of bait fish available for harvest.

The results of this study indicate that the amount of bait fish available for harvest decreases with successive harvests, and that the effects of harvest extend beyond the harvest site proper. Therefore, when several bait fishermen are licensed to use the same area, the harvest activities of any one individual can affect the harvest of the other individuals. This 'competition' between bait fishermen reduces their effectiveness in managing the resource for sustained yields. For example, a bait fisherman can gain little by leaving a particular area unharvested until creek chub have completed spawning, if another fisherman harvests it prior to spawning. It appears that the most satisfactory method of allowing bait fishermen to assume some responsibility for management is to institute a system of exclusive use based on watersheds. The regression equations developed in this study, used in conjunction with knowledge of stream dimensions, might provide a basis for an equitable division of harvest areas.

Although the results of this study indicate that harvest can decrease bait fish biomass in the following years, little insight has been gained regarding what proportion of existing biomass can be harvested on a sustained basis. The decline in mean fish weight during four years of harvest at the 50 percent level, as reported by Larimore (1954), suggests that overharvest was occurring. In this study, biomass was reduced the following year at two sites where harvest was estimated to be 71 percent and 34 percent of the biomass present the previous year. However, further research is required before a sound basis for establishing a catch quota can be developed.

RESEARCH

Several areas exist where research could potentially improve the ability of resource managers to effectively manage the bait fish resource. There is a need to undertake a well-designed study of the effects of harvest on species composition, biomass, and abundance of bait fish communities. In order to understand the processes involved, growth, mortality, and fecundity should be examined. Several seasons of harvest (at least 3) should be monitored, if a realistic picture is to

be obtained.

An investigation of the year to year variation in unharvested bait fish communities is required. Perhaps periodic shortages in bait fish can be attributed to climatic variation rather than overharvest.

The effects of physico-chemical parameters on bait fish biomass beyond the ranges encountered in this study should be examined. Of particular interest is the expansion of the data base to include deeper sites and soft-water streams. The potential for habitat rehabilitation or enhancement to increase bait fish production should be evaluated.

Many of the streams from which bait fish are now harvested also contain significant game fish populations. Predation by game fish may significantly reduce bait fish biomass. One site was encountered in this study where pike (*Esox lucius*) made up 25% of $\hat{B}_T$. No cyprinids were captured at this site; in fact, the only legal bait species captured was white sucker (*Catostomus commersoni*), and all individuals exceeded 140 mm standard length. I suspect that predation by pike was the principal reason for the absence of cyprinids at this site. The question which logically follows is: *What effect does the harvest of bait fish have on game fish populations?* The interactions between these groups should definitely be investigated.

CONCLUSIONS

It is widely recognized that a biological basis for the effective management of bait fish does not exist at this time. The results of this study provide new insights, but do not provide a definitive answer to the ultimate question: *How many bait fish can be harvested from Ontario streams without adversely affecting either bait fish or game fish resources?* Further research will bring us closer to the answer, but in the interim, at least, a change in management policy to allow individual bait fishermen exclusive use of prescribed watersheds or portions of watersheds may well be the most effective management technique.

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TABLES

Table 1. Location of sites at which biomass was estimated.

SITE	STREAM NAME	DRAINAGE CODE[a]	LATITUDE	LONGITUDE
SR1	Holland River (west branch)	22-0912	44°00'	79°41'
SR2	Unnamed	22-0912	44°01'	79°34'
SR3	Unnamed	22-0912	44°02'	79°34'
HR1	Holland River (east branch)	22-0913	44°02'	79°28'
HR2	Bogart Creek	22-0913	44°03'	79°24'
JR1 and JR2	Jersey River	22-0914	44°10'	79°26'
BR1	Beaverton River	22-0919	44°21'	79°02'
SP2	Unnamed (Speed River)	23-0610	43°42'	80°19'
MR1	Mallett River	23-0613	43°49'	81°43'
CC1	Carroll Creek	23-0614	43°43'	80°30'
CC2	Carroll Creek	23-0614	43°42'	80°30'
SC1	Spencer Creek	24-0203	43°49'	80°04'
GC1 and GC2	Grindstone Creek	24-0204	43°21'	79°57'
LC1 and LC2	Limestone Creek	24-0206	43°27'	79°53'

[a] Source: Ontario Ministry of the Environment, 1973. Map 3002-2, Southern Ontario Drainage Basins, Water Quantity Management Branch.

Table 2. Physico-chemical characteristics of the sites at which biomass was estimated.

SITE	DATE OF COLLECTION	AREA (m^2)	VOLUME (m^3)	MEAN DEPTH (m)	MAXIMUM DEPTH (m)	ALKALINITY ($mg \cdot \ell^{-1}$)	HARDNESS ($mg \cdot \ell^{-1}$)	CONDUCTIVITY (umhos at 25°C)	TDS ($mg \cdot \ell^{-1}$)
BR1-U	01/07/80	113.0	14.4	0.13	0.30	265	310	550	359
BR1-D	01/07/80	114.6	16.5	0.14	0.25	265	310	550	359
SR1	03/07/80	78.9	13.2	0.16	0.28	278	300	520	343
JR2	07/08/80	97.7	62.4	0.64	1.10	340	426	820	536
JR1	11/08/80	95.4	24.4	0.26	0.50	340	426	820	536
HR1	12/08/80	70.9	15.3	0.22	0.45	265	308	550	359
HR2	12/08/80	59.5	14.1	0.24	0.40	221	240	480	311
SR2	14/08/80	141.0	25.3	0.18	0.60	237	270	500	327
SR3	14/08/80	91.0	10.7	0.12	0.25	243	282	500	327
SP2	26/06/81	76.2	18.0	0.24	0.55	262	310	500	327
LC1	29/06/81	44.8	11.9	0.27	0.45	264	312	510	327
LC2	29/06/81	68.6	25.1	0.37	0.75	264	312	510	327
GC1	30/06/81	45.8	27.6	0.60	1.30	218	360	580	375
GC2	10/07/81	42.2	14.4	0.34	0.80	218	360	580	375
SC1	15/07/81	79.3	8.6	0.11	0.20	239	282	420	279
MR1	27/07/81	241.8	55.6	0.23	0.45	261	590	470	311
CC1	04/08/81	118.4	39.7	0.34	0.70	312	392	600	392
CC2	04/08/81	50.7	15.5	0.31	0.70	293	364	590	392

Table 3. Species present at 18 sites where biomass was estimated.

SPECIES	SITES																		# OF SITES
	CC1	MR1	GC1	BR1-U	CC2	GC2	SP2	JR1	BR1-D	JR2	LC1	LC2	SR3	SR1	SR2	SC1	HR1	MR2	
Semotilus atromaculatus	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	18
Catostomus commersoni	X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	17
Rhinichthys atratulus	X		X	X	X	X	X		X		X	X	X	X	X	X	X	X	15
Pimephales notatus	X	X	X	X	X	X	X				X	X	X	X	X		X		13
Notropis cornutus	X	X	X	X	X		X	X	X	X	X	X		X	X				13
Etheostoma nigrum	X	X	X		X	X		X		X	X	X	X	X	X				12
Culaea inconstans	X	X	X	X	X	X	X	X	X				X			X			11
Pimephales promelas	X		X	X	X	X	X	X	X	X				X					10
Semotilus margarita	X		X	X		X	X		X	X			X	X		X			10
Chrosomus eos	X		X	X		X	X	X	X	X									8
Notropis heterolepis	X	X	X		X	X		X		X								X	8
Cottus bairdi				X			X		X				X		X	X	X	X	8
Rhinichthys cataractae				X				X	X	X	X	X		X			X		8
Hybognathus hankinsoni	X		X		X	X	X	X											6
Umbra limi			X	X		X	X		X							X			6
Nocomis spp.	X	X			X						X	X							5
Ambloplites rupestris	X	X			X														3
Hypentelium nigricans		X									X	X							3
Etheostoma flabellare		X					X				X								3
Etheostoma microperca	X	X			X								X			X			3
Micropterus salmoides												X				X			2
Micropterus dolomieui		X										X							2
Etheostoma caeruleum		X									X								2
Chrosomus neogaeus			X			X													2
Lepomis gibbosus				X					X										2
Notemigonus chrysoleucas								X		X									2
Ictalurus nebulosus								X		X									2
Etheostoma exile	X														X				1
Clinostomus elongatus																			1
Number of Species	16	14	14	13	13	13	13	12	11	11	11	10	9	9	8	8	6	5	

Table 4. The estimated total biomass ($\hat{B}_T$) and saleable biomass ($\hat{B}_E$), the proportion of $\hat{B}_T$ which was saleable ($\hat{B}_E$:$\hat{B}_T$), the estimated abundance ($\hat{a}$) and overall mean weight ($\overline{wt}$) at 18 sites.

SITE	$\hat{B}_T$ ($g \cdot m^{-2}$)	$\hat{B}_E$ ($g \cdot m^{-2}$)	$\hat{B}_E$:$\hat{B}_T$ (%)	$\hat{a}$ (m^{-2})	$\overline{wt}$ (g)
SP2	11.0	6.7	61	5.0	2.2
LC1	37.2	36.2	97	5.1	7.3
LC2	89.5	88.1	98	6.2	14.5
GC1	247.3	208.2	84	55.8	4.4
GC2	51.5	33.6	65	24.7	2.1
SC1	5.6	3.6	64	1.6	3.5
MR1	6.5	3.9	60	3.0	2.1
CC1	51.2	44.3	87	14.9	3.4
CC2	30.3	19.2	63	10.5	2.9
BR1-U	12.0	7.9	66	5.9	2.0
BR1-D	3.8	0.8	21	1.9	2.0
SR1	14.5	5.5	38	5.2	2.8
SR2	17.7	15.5	88	3.4	5.2
SR3	3.3	0.3	9	2.6	1.3
JR2	78.4	68.6	88	13.3	5.9
JR1	31.4	14.1	45	30.5	1.0
HR1	9.7	9.2	95	1.1	8.6
HR2	6.0	0.0	0	8.4	0.7

Table 5. Regression equations developed in this study.

Equation 1:

$$\log \hat{B}_T = 2.5584 + 2.0541 \log \bar{d}$$

$$n = 18,\ p<0.01,\ r^2 = 0.74$$

Equation 2:

$$\log (\hat{B}_E + 1) = 2.5428 + 2.3165 \log \bar{d}$$

$$n = 17,\ p<0.01,\ r^2 = 0.77$$

Equation 3:

$$\log (\hat{B}_E + 1) = -0.4096 + 1.18 \log \hat{B}_T$$

$$n = 18,\ p<0.01,\ r^2 = 0.93$$

Equation 4:

$$\log \hat{a} = 0.223 + 2.142 \bar{d}$$

$$n = 18,\ p<0.05,\ r^2 = 0.485$$

Table 6. The estimated number ($\hat{N}$), total biomass ($\hat{B}_T$) and mean weight ($\overline{wt}$) of each species in three successive catches at GC1. I = 30/06/81, II = 24/07/81, III = 17/08/81.

SPECIES	STANDARD LENGTH (mm)	$\hat{N}$			$\hat{B}$ (g)			$\overline{wt}$ (g)		
		I	II	III	I	II	III	I	II	III
Semotilus margarita	31- 95	818	478	247	4858.4	2420.6	1122.6	5.9	5.1	4.5
Catostomus commersoni	39-107	27	5	4	1662.2	247.5	263.8	61.6	49.5	66.0
Chrosomus eos	28- 58	795	395	98	1428.5	744.0	173.2	1.8	1.9	1.8
Chrosomus neogaeus	35- 66	309	144	18	980.5	435.6	73.1	3.2	3.0	4.1
Semotilus atromaculatus	29-177	78	65	78	882.1	825.2	652.6	11.3	12.7	8.4
Hybognathus hankinsoni	36- 68	184	53	8	665.7	191.5	26.0	3.6	3.6	3.3
Notropis cornutus	42- 99	14	0	1	169.1	0.0	1.3	12.1	-	1.3
Pimephales promelas	37- 71	63	20	5	191.1	57.3	21.5	3.0	2.9	4.3
Pimephales notatus	29- 71	48	103	11	157.8	272.7	16.5	3.3	2.6	1.5
Etheostoma nigrum	20- 59	62	105	21	111.6	224.9	32.9	1.8	2.1	1.6
Notropis heterolepis	37- 46	73	13	0	98.3	18.9	0.0	1.3	1.5	-
Umbra limi	67- 94	6	3	1	52.2	34.3	9.3	8.7	11.4	9.3
Rhinichthys atratulus	42- 78	7	18	39	38.5	84.1	288.3	5.5	4.7	7.4
Culaea inconstans	14- 49	71	734	571	30.6	240.5	214.5	0.4	0.3	0.4
Total		2555	2136	1102	11326.6	5797.1	2895.6	4.4	2.7	2.6
Total - *Culaea inconstans*		2484	1402	531	11296.0	5556.6	2681.1	4.5	4.0	5.0
Bait fish[a]		1525	735	304	9588.1	4174.6	2357.4	6.3	5.7	7.8
% Bait fish		61	52	57	85	75	88			

[a]Smallest size class of *Semotilus margarita* and *S. atromaculatus* excluded.

Table 7. The estimated number ($\hat{N}$), total biomass ($\hat{B}_T$) and mean weight ($\overline{wt}$) of each species in three successive harvests at LC2. I = 29/06/81, II = 24/07/81, III = 17/08/81.

SPECIES	STANDARD LENGTH (mm)	$\hat{N}$			$\hat{B}$ (g)			$\overline{wt}$ (g)		
		I	II	III	I	II	III	I	II	III
Catostomus commersoni	48-227	157	65	33	3308.3	1317.7	668.8	21.1	20.3	20.3
Semotilus atromaculatus	44-170	138	25	42	1275.1	647.0	497.0	9.2	25.9	11.8
Hypentelium nigricans	64-200	17	17	6	988.6	205.4	203.2	58.2	12.1	33.9
Notropis cornutus	35-112	46	20	15	339.5	216.8	104.4	7.4	10.8	7.0
Etheostoma nigrum	28- 56	42	8	2	67.9	10.9	2.0	1.6	1.4	1.0
Pimephales notatus	24- 73	10	7	17	50.8	25.2	37.0	5.1	3.6	2.2
Rhinichthys atratulus	44- 63	10	0	0	39.5	0.0	0.0	4.0	-	-
Nocomis sp.	125-140	1	0	2	39.4	0.0	107.0	39.4	-	53.5
Micropterus dolomieui	37-110	2	5	1	28.3	41.2	3.8	14.2	8.2	3.8
Rhinichthys cataractae	59	1	0	0	4.9	0.0	0.0	4.9	-	-
Hybognathus hankinsoni	59	0	1	0	0.0	3.6	0.0	-	3.6	-
Etheostoma caeruleum	39	0	1	0	0.0	1.2	0.0	-	1.2	-
Total		424	149	118	6142.3	2469.0	1623.2	14.5	16.6	13.8
Bait fish		380	135	98	6046.1	2415.7	1580.4	15.9	17.9	16.1
% Bait fish		90	91	83	98	98	97			

Table 8. The estimated number ($\hat{N}$) and biomass ($\hat{B}$) per 100 m^2 and the mean weight of the fishes captured at JR2 on 07/08/80 and 18/08/81.[a]

SPECIES	STANDARD LENGTH (mm)	$\hat{N}$		$\hat{B}$		$\overline{wt}$	
		1980	1981	1980	1981	1980	1981
Semotilus atromaculatus	39- 56	3	0	9.6	0	3.1	-
	53-159[b]	200	112	4308.4	2647.5	21.8	23.7
Catostomus commersoni	22- 50	67	9	72.2	17.0	1.1	1.8
	61-171[b]	61	50	1482.3	1348.6	23.2	27.1
Notropis cornutus	30- 40	0	14	0.0	10.8	-	0.8
	53-102[b]	123	46	1051.8	446.4	8.6	9.6
Ictalurus nebulosus	35-171	10	2	320.6	144.5	34.8	60.9
Pimephales promelas	21- 57	127	184	302.4	304.5	2.4	1.7
Culaea inconstans	14- 42	710	215	200.4	54.8	0.3	0.3
Etheostoma nigrum	28- 49	16	8	22.4	6.3	1.4	0.8
Notemigonus chrysoleucas	62- 74[b]	2	0	12.6	0.0	6.2	-
Lepomis gibbosus	59	1	0	8.6	0.0	8.4	-
Chrosomus eos	24- 46	10	13	8.0	13.1	0.8	1.0
Semotilus margarita	40- 60	2	0	5.1	0.0	2.5	-
Hybognathus hankinsoni	59[b]	0	1	0.0	5.0	-	4.2
Total		1332	654	7804.4	4998.5	5.9	7.6
Excluding *C. inconstans*		622	439	7604.0	4943.7	12.2	11.3
$\hat{B}_E$		386	209	6855.1	4447.5	17.7	21.3

[a] Mean weight may not equal $\hat{B} \div \hat{N}$ as $\hat{B}$ and $\hat{N}$ were extrapolated to 100 m^2 independently.

[b] Included in $\hat{B}_E$

Table 9. The estimated number ($\hat{N}$) and biomass ($\hat{B}$) per 100 m^2 and the mean weight of the fishes captured at SR2 on 14/08/80 and 19/08/81.[a]

SPECIES	STANDARD LENGTH (mm)	$\hat{N}$		$\hat{B}$		$\overline{wt}$	
		1980	1981	1980	1981	1980	1981
Semotilus atromaculatus	20- 41	43	60	25.0	34.8	0.6	0.6
	46-138[b]	60	39	787.2	506.8	15.0	12.9
Catostomus commersoni	25- 48	9	29	6.4	36.0	0.8	1.2
	69-225[b]	12	2	522.1	73.4	43.3	42.9
Etheostoma nigrum	14- 56	152	307	121.8	225.9	0.8	0.7
Rhinichthys atratulus	16- 30	12	20	2.8	5.6	0.2	0.3
	40- 70[b]	25	12	90.4	52.5	3.6	4.4
Notropis cornutus	20- 35	7	8	1.3	2.7	0.2	0.4
	50- 93[b]	6	0	49.6	0.0	7.8	-
Cottus bairdi	24- 72	2	21	23.8	31.7	11.2	1.5
Clinostomus elongatus	54- 73[b]	4	2	20.3	2.4	4.8	1.4
Rhinichthys cataractae	22- 40	10	17	3.3	8.6	0.4	0.5
Micropterus salmoides	61	0	1	0.0	4.5	-	5.3
Total		342	518	1654.0	984.9	4.8	1.9
$\hat{B}_E$		107	55	1469.6	635.1	13.7	11.5

[a] Mean weight may not equal $\hat{B} : \hat{N}$ as $\hat{B}$ and $\hat{N}$ were extrapolated to 100 m^2 independently.
[b] Included in $\hat{B}_E$.

Table 10. The estimated number ($\hat{N}$) and biomass ($\hat{B}$) per 100 m^2 and the mean weight of the fishes captured at HR2 on 12/08/80 and 18/08/81.[a]

SPECIES	STANDARD LENGTH (mm)	$\hat{N}$		$\hat{B}$		$\overline{wt}$	
		1980	1981	1980	1981	1980	1981
Semotilus atromaculatus	23- 44	553	196	435.8	184.2	0.8	0.9
Catostomus commersoni	23 52	262	188	142.0	271.1	0.5	1.4
	60-109[b]	0	20	0.0	216.9	-	10.7
Lepomis gibbosus	37- 65	3	13	9.9	69.6	3.0	5.2
Rhinichthys atratulus	24- 39	15	51	7.4	30.0	0.5	0.6
Cottus bairdi	34- 73	2	55	1.0	85.0	0.6	1.5
Notropis cornutus	30- 44	0	105	0.0	102.0	-	1.0
Hypentelium nigricans	66[b]	0	1	0.0	6.3	-	4.7
Pimephales promelas	35	0	1	0.0	0.9	-	0.7
Total		835	630	596.1	966.0	0.7	1.5
$\hat{B}_E$		0	21	0.0	223.2		

[a] Mean weight may not equal $\hat{B} : \hat{N}$ as $\hat{B}$ and $\hat{N}$ were extrapolated to 100 m^2 independently.
[b] Included in $\hat{B}_E$.

Table 11. The estimated number ($\hat{N}$) and biomass ($\hat{B}$) per 100 m^2 and the mean weight of fishes captured at SR3 on 14/08/80 and 19/08/81.[a]

SPECIES	STANDARD LENGTH (mm)	$\hat{N}$		$\hat{B}$		$\overline{wt}$	
		1980	1981	1980	1981	1980	1981
Etheostoma nigrum	17- 38	102	203	40.0	97.8	0.4	0.5
	39- 60	65	40	124.8	81.8	1.9	2.1
Catostomus commersoni	33- 48	43	6	54.7	10.9	1.3	1.8
	79[b]	0	1	0.0	11.1	-	9.0
Semotilus atromaculatus	30- 55	7	20	18.5	16.8	2.8	0.9
	56- 92[b]	3	4	29.9	15.6	9.1	4.2
Pimephales notatus	45- 65	9	0	24.5	0.0	2.8	-
Micropterus salmoides	38- 57	5	14	13.2	28.9	2.4	2.1
Rhinichthys cataractae	27- 42	15	126	8.8	90.7	0.6	0.7
Rhinichthys atratulus	20- 46	8	17	8.7	7.5	1.1	0.4
Semotilus margarita	40- 45	3	0	4.4	0.0	1.3	-
Cottus bairdi	41	1	0	1.6	0.0	1.5	-
Etheostoma exile	47- 49	0	2	0.0	4.8	-	2.0
Notropis cornutus	37- 38	0	2	0.0	2.2	-	0.9
Total		261	435	329.1	368.1	1.3	0.8
$\hat{B}_E$		3	5	29.9	26.7		

[a] Mean weight may not equal $\hat{B} \div \hat{N}$ as $\hat{B}$ and $\hat{N}$ were extrapolated to 100 m^2 independently.

[b] Included in $\hat{B}_E$.

FIGURES

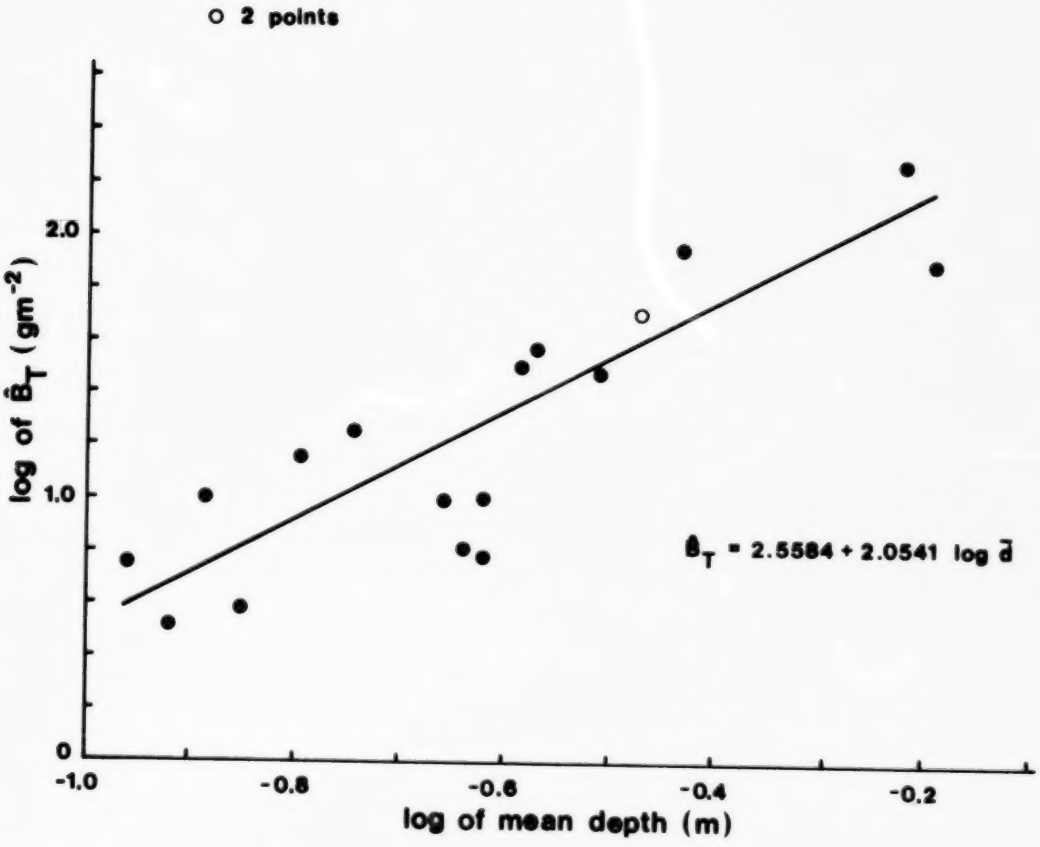

Figure 1. Relationship between the log of mean depth and the log of estimated total biomass.

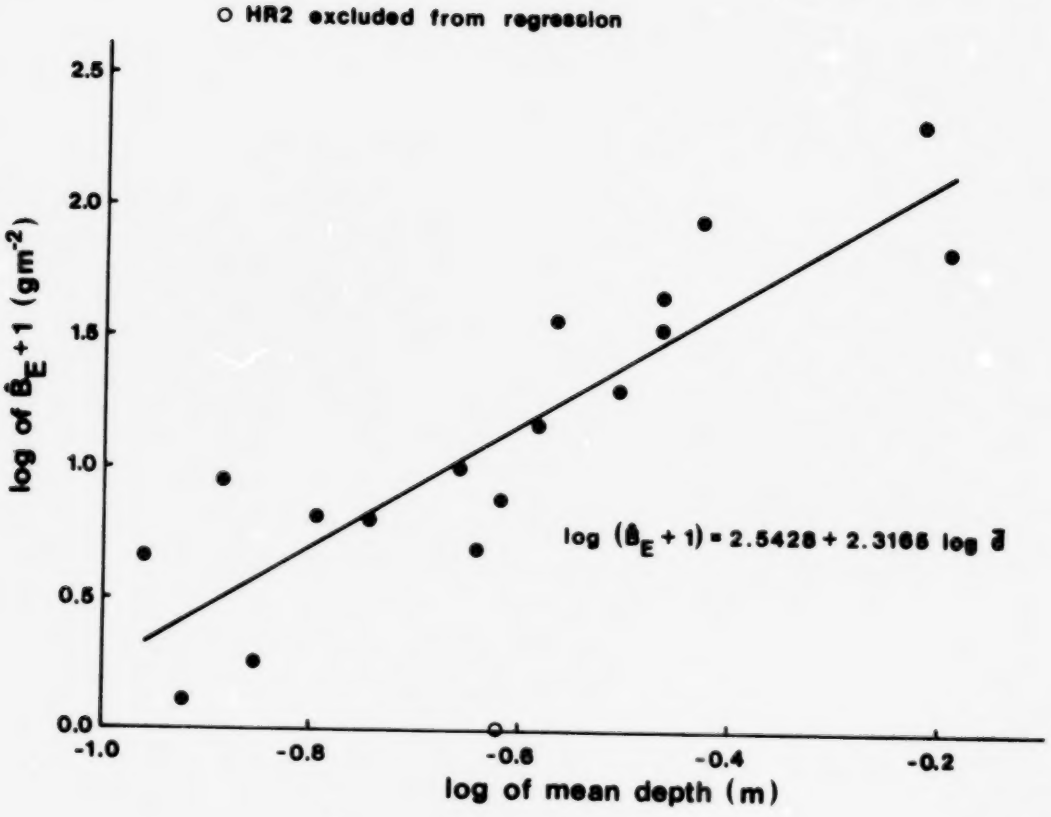

Figure 2. Relationship between the log of mean depth and the log of estimated bait fish biomass.

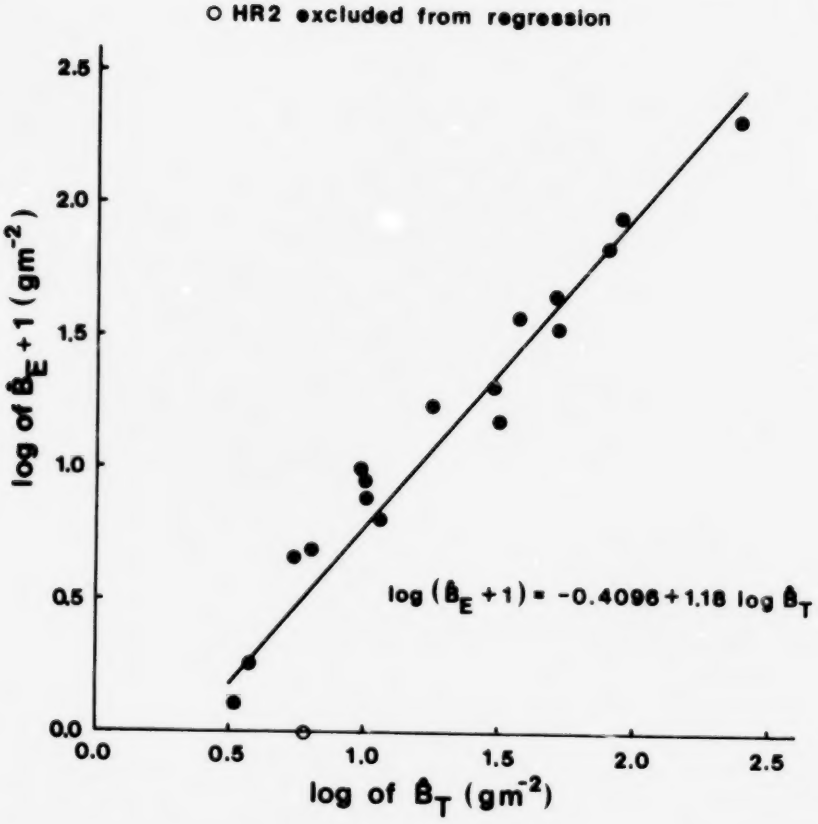

Figure 3. Relationship between the log of estimated total biomass and the log of estimated bait fish biomass.

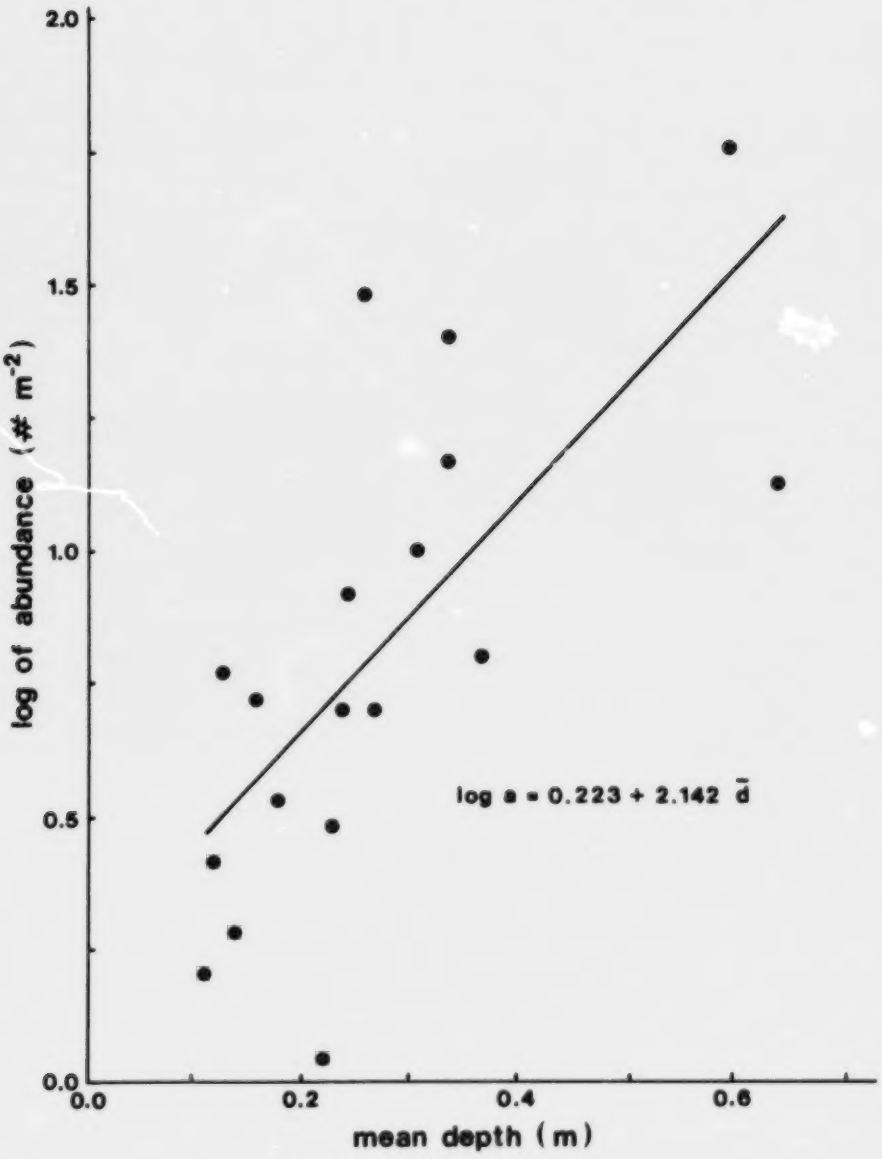

Figure 4. Relationship between mean depth and the log of abundance.

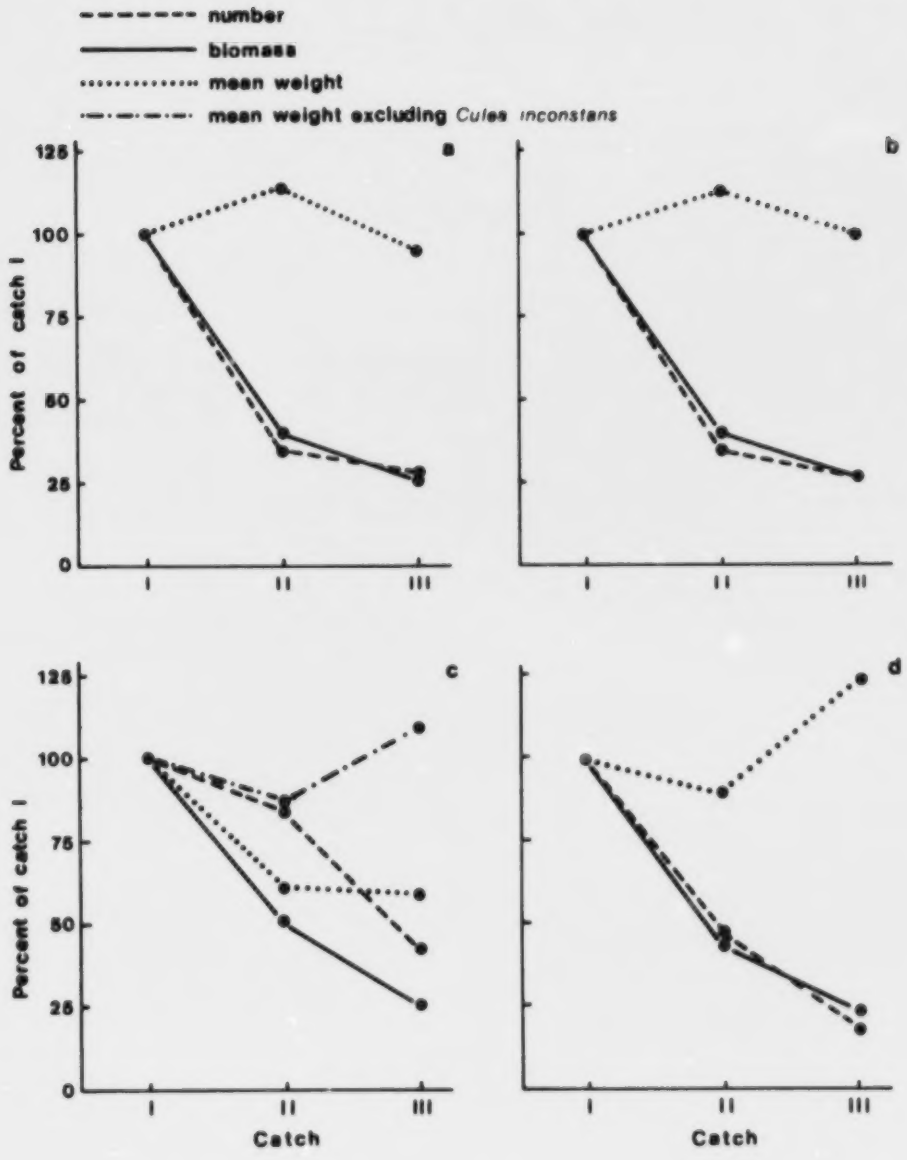

Figure 5. Plots of estimated number, mean weight, and biomass in successive harvests: a) all fish at LC2, b) bait fish at LC2, c) all fish at GC1, d) bait fish at GC1.

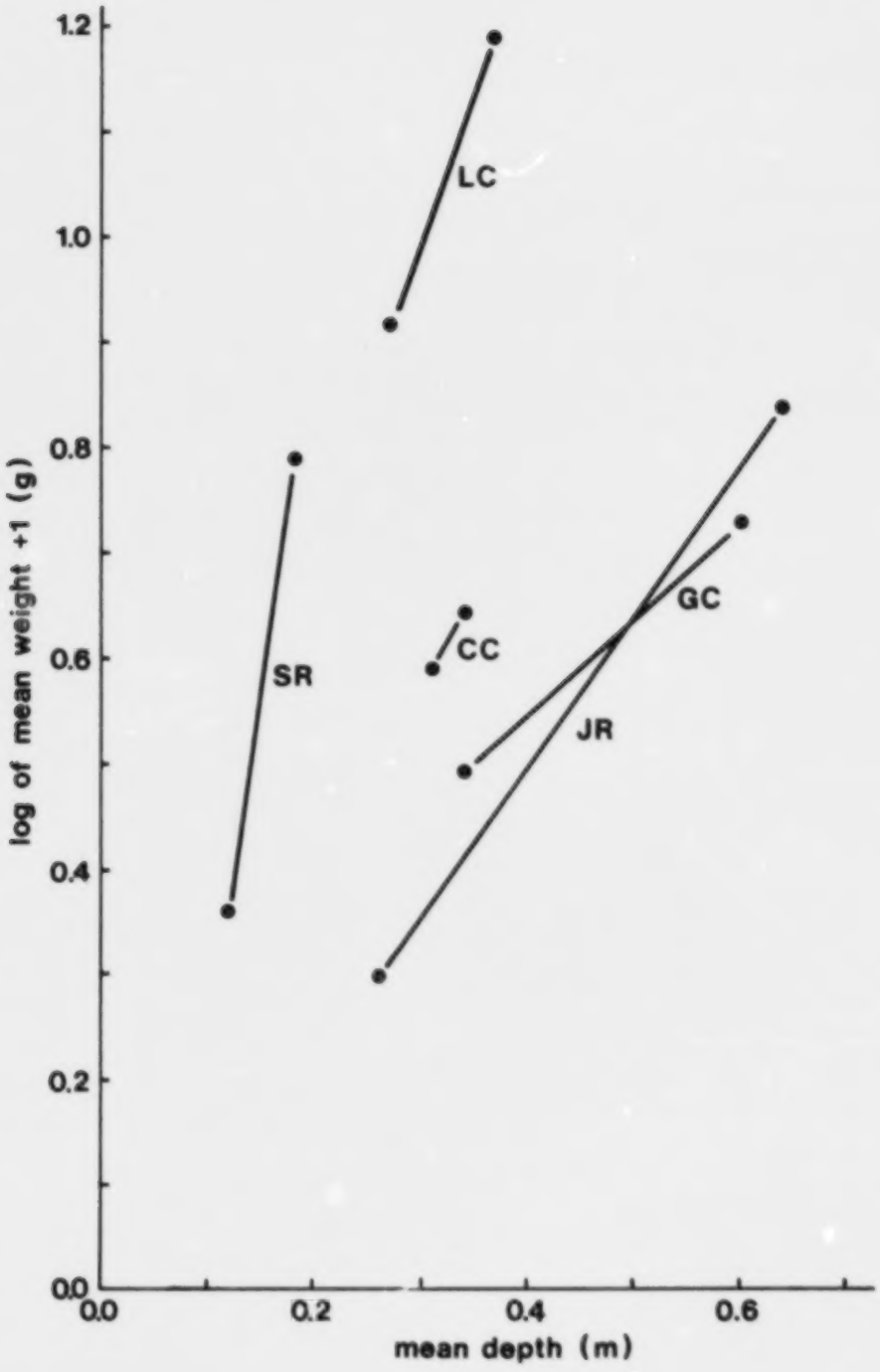

Figure 6. Relationship between mean depth and log of mean fish weight at five locations where two sites in close proximity were sampled.

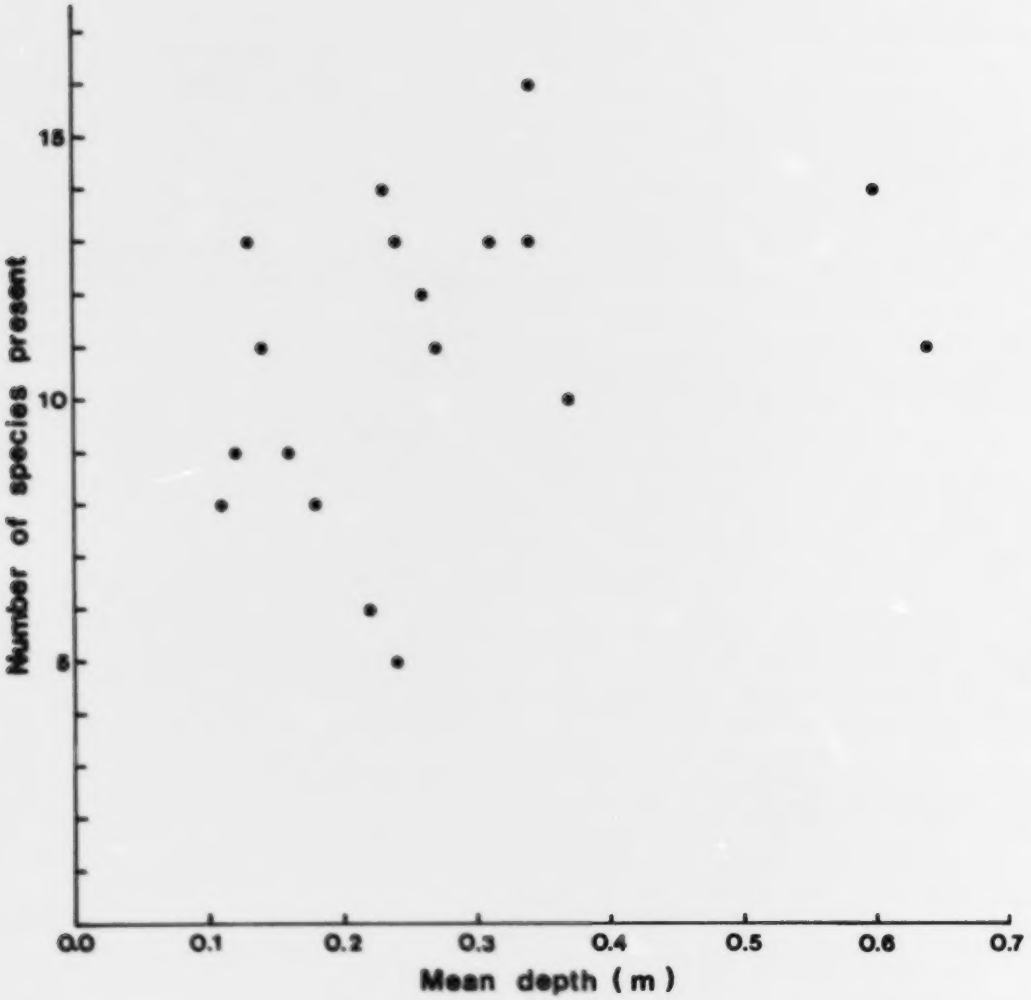

Figure 7. Relationship between mean depth and the number of species present.

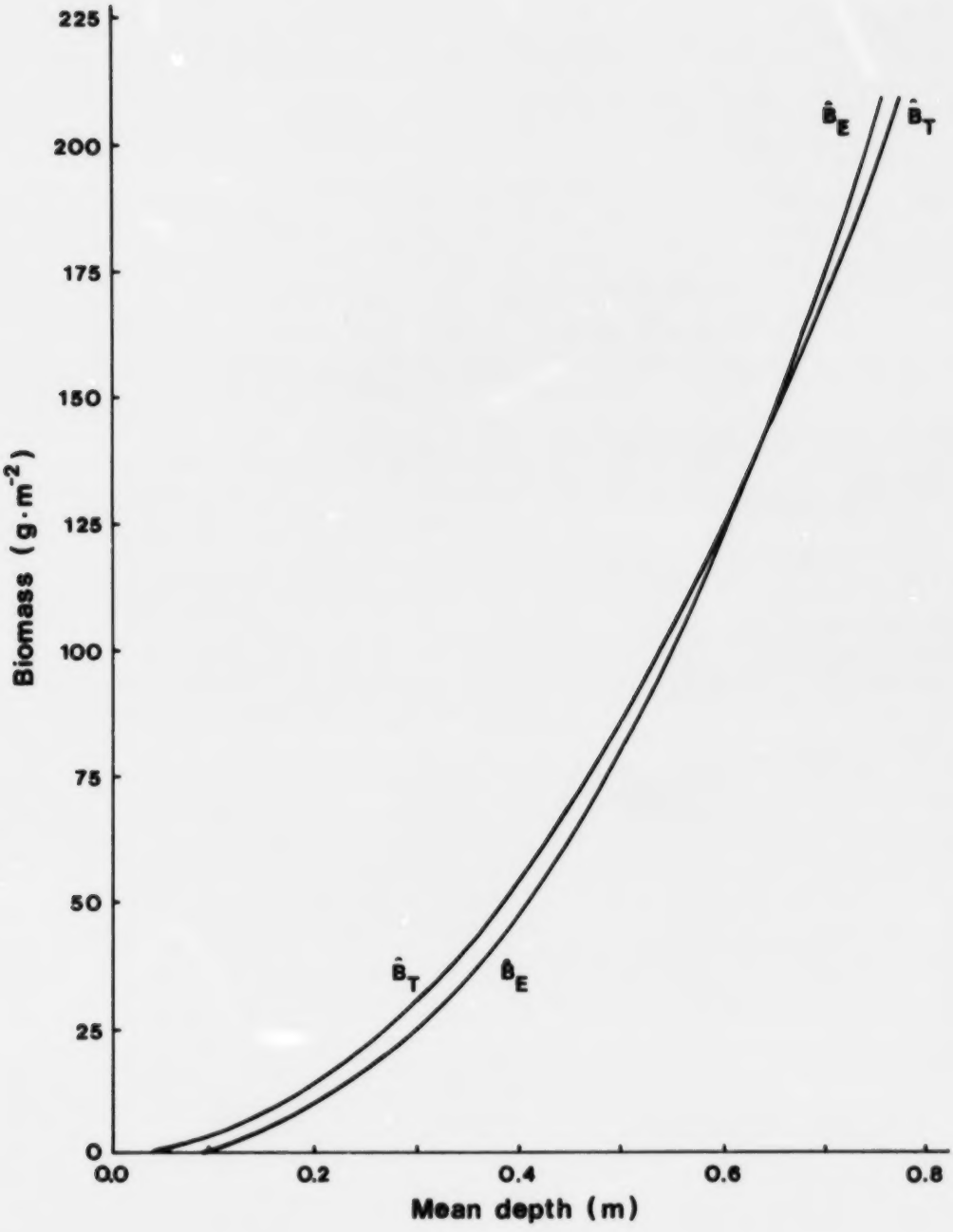

Figure 8. Relationship between mean depth and biomass as indicated by regression equations $\log \hat{B}_T = 2.5584 + 2.0541 \log \bar{d}$ and $\log (\hat{B}_E + 1) = 2.5428 + 2.3165 \log \bar{d}$ showing obvious error at depths exceeding -0.66 m.

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